ÉCOLE POLYTECHNIQUE
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Study of plasma filament motion and their active control

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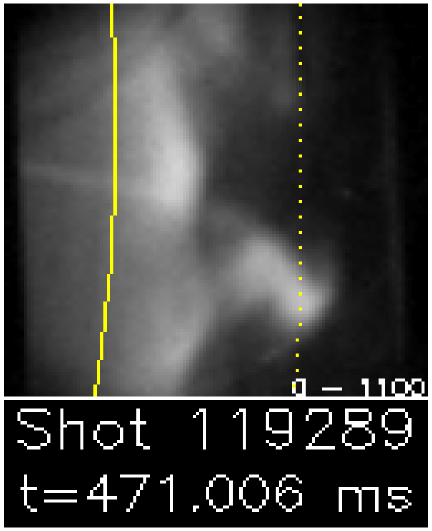
Introduction

Propagating plasma filaments are an important element of edge turbulence.

They influence

- Plasma-wall interactions
- Divertor efficiency
- Confinement?



Courtesy of R. Maqueda

Mechanism of filament/blob motion

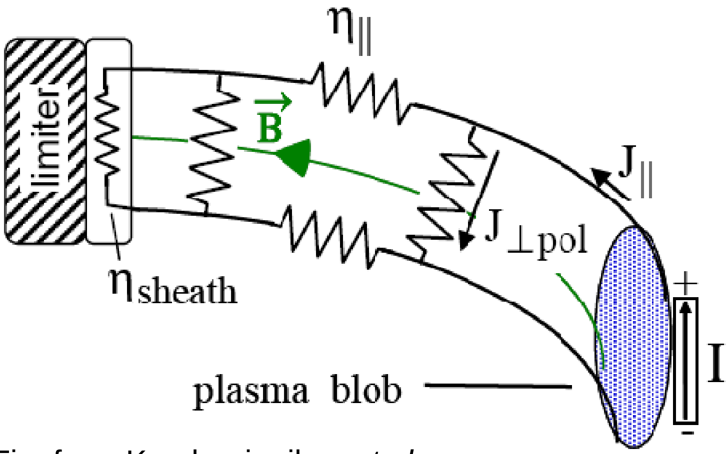
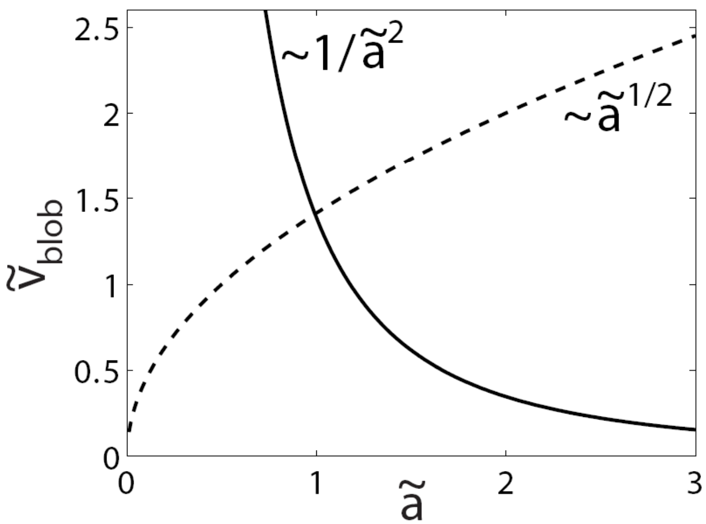


Fig. from Krasheninnikov *et al.*

The radial velocity of a filament/blob is a crucial parameter as it governs the fraction of energy and particles which are transported to the wall

Scaling laws for filament/blob velocity



Damping due to ion-polarization currents[2,3]

Damping due to parallel currents[1]

Normalization:

$$v^*_{blob} = \left(\frac{2L\rho_s^2}{R^3}\right)^{1/5} c_s$$

$$a^* = \left(\frac{4L^2}{\rho_s R}\right)^{1/5} \rho_s$$

L: connection length
R: major radius

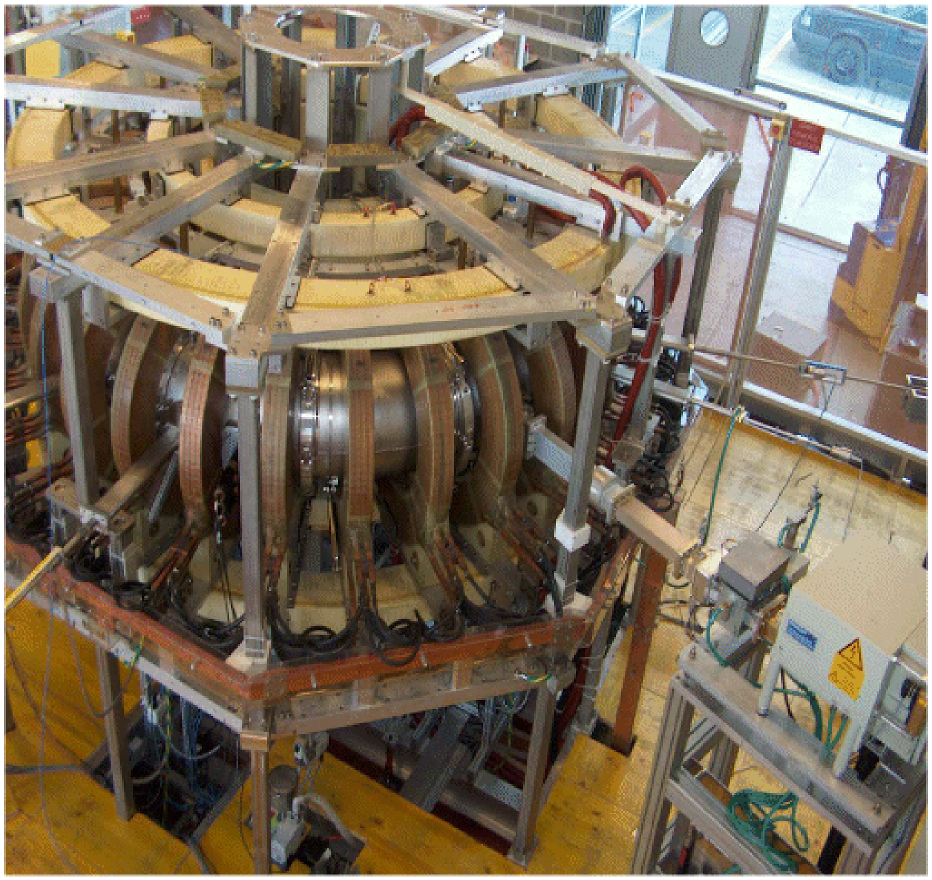
Presentation of:

- In situ measurements of blob motion in a simple geometry
- Wide scan in normalized blob size ã by varying ion mass
- Generalization of above scaling laws
- First attempt to actively influence blob motion

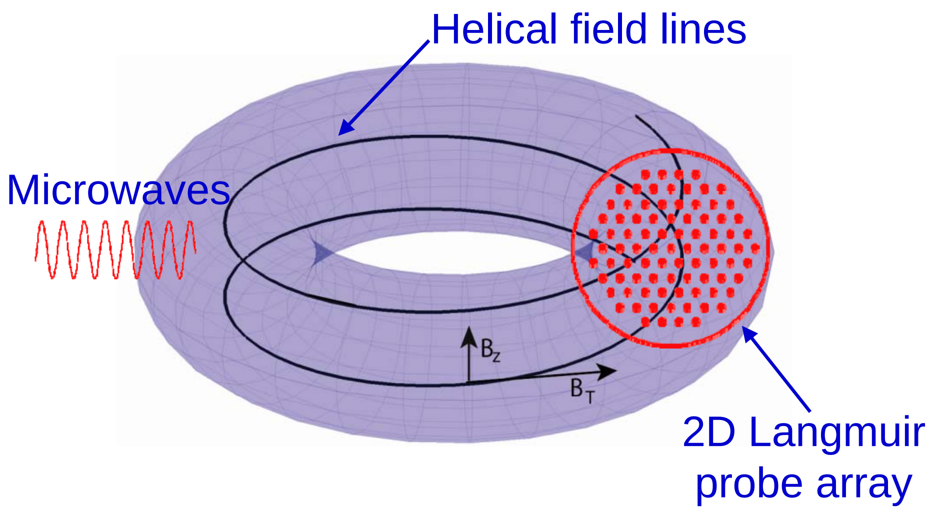
[1] S. I. Krasheninnikov, PLA 2001 [2] O. E. Garcia et al., POP 2005 [3] J. R. Myra and D. A. D'Ippolito, POP 2005

The TORPEX device

- Toroidal device: R=1 m, a=0.2 m
- Open field lines, ∇B and curvature



[A. Fasoli et al., POP 2006]



Parameters

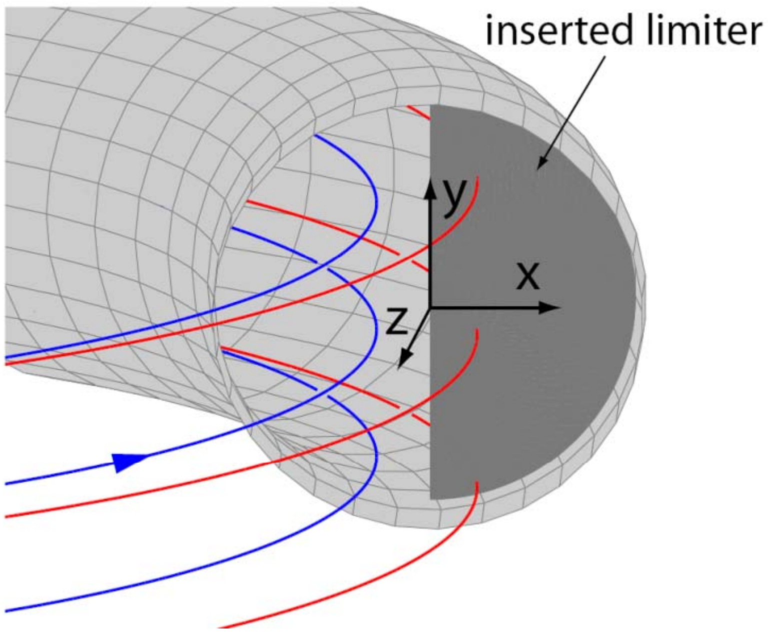
$$|B_T| \approx 76mT \qquad n_e \leq 10^{17} m^{-3}$$

$$|B_z / B_T| \leq 5\% \qquad T_e \leq 15eV$$

$$T_i << T_e$$

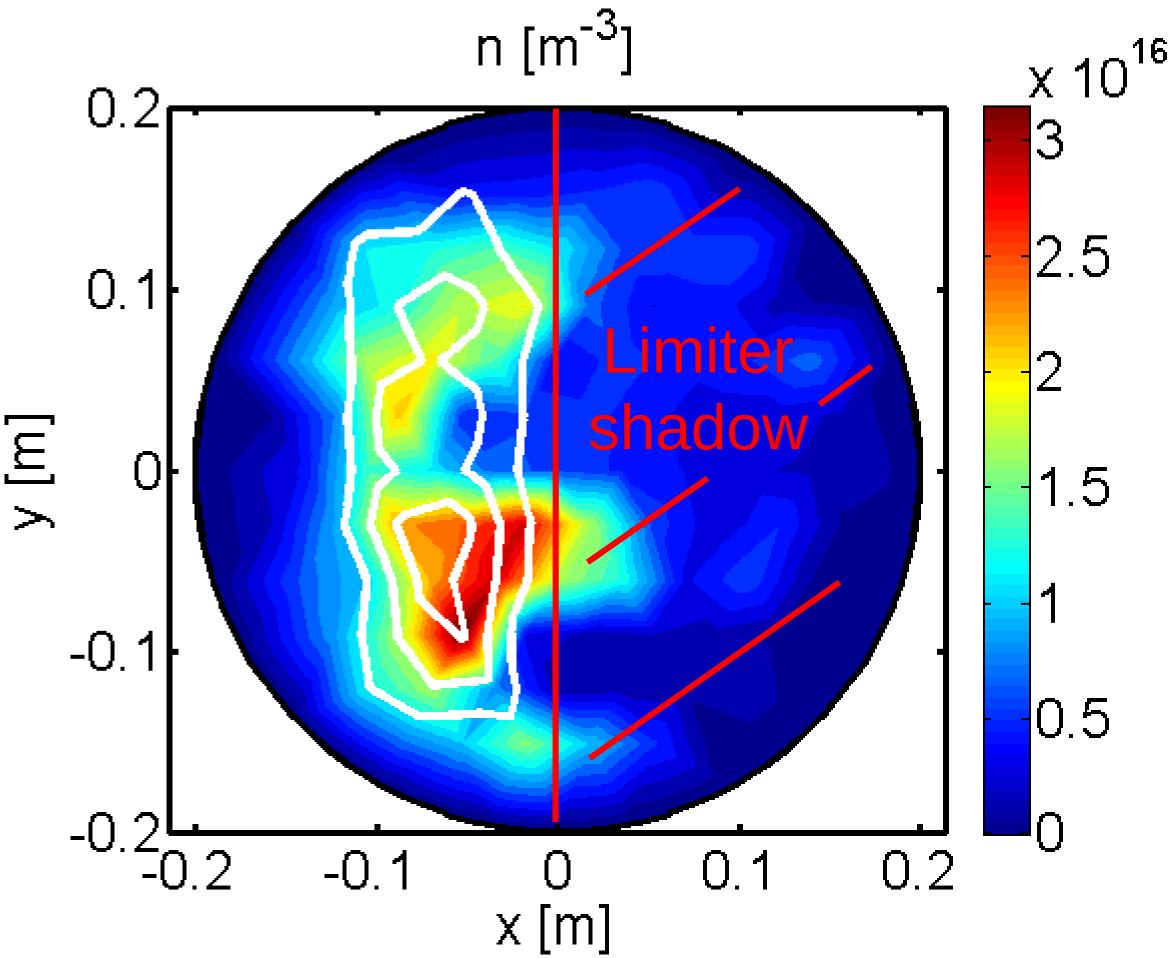
Filaments in a simple geometry

- Steel limiter in low-field side
  - ➡ Region with
    - Constant curvature along field lines
    - Nearly constant connection length
    - Near-perpendicular incidence of magnetic field lines on limiter
  - ➡ No complicating effects such as
    - Magnetic shear
    - Changing field-line curvature
    - Wall tilt
    - Finite beta effects



Target plasma

Snapshot of density profile in H_2 plasma



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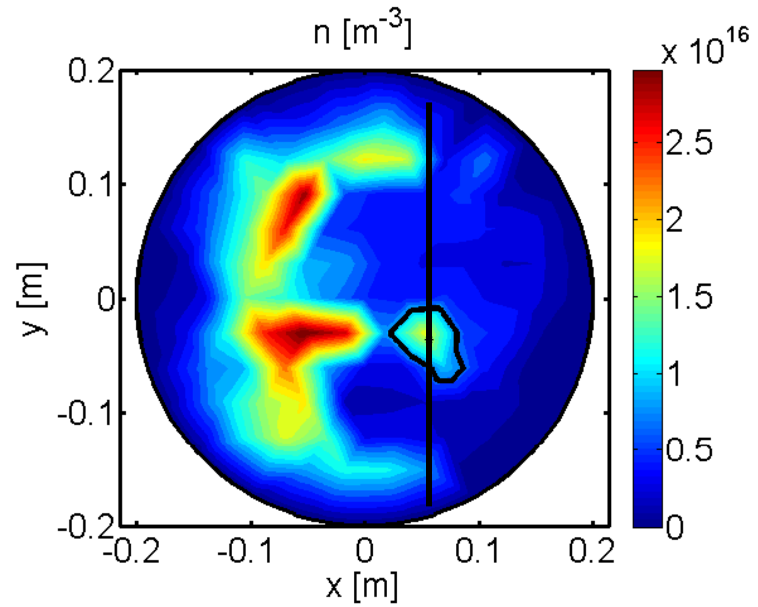
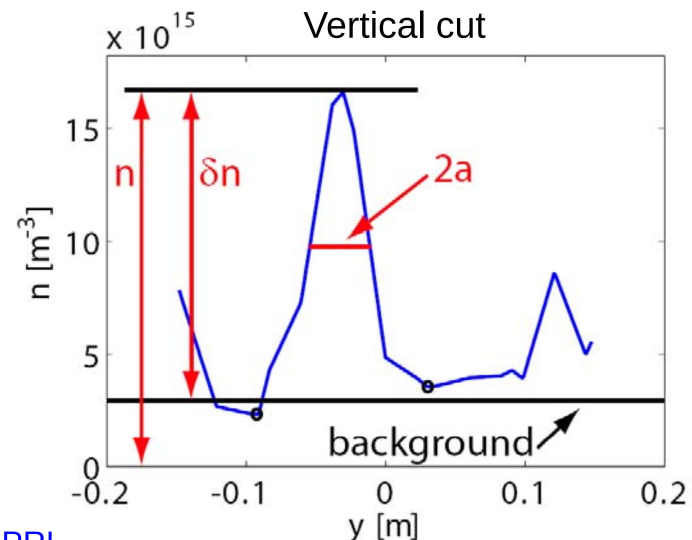
Analysis of filament/blob motion

- Blobs identified by pattern recognition[1]
- Automatic evaluation of[2]
  - Radial velocity — v
  - Vertical size — a
  - Peak density — n
  - Peak density above background — δn

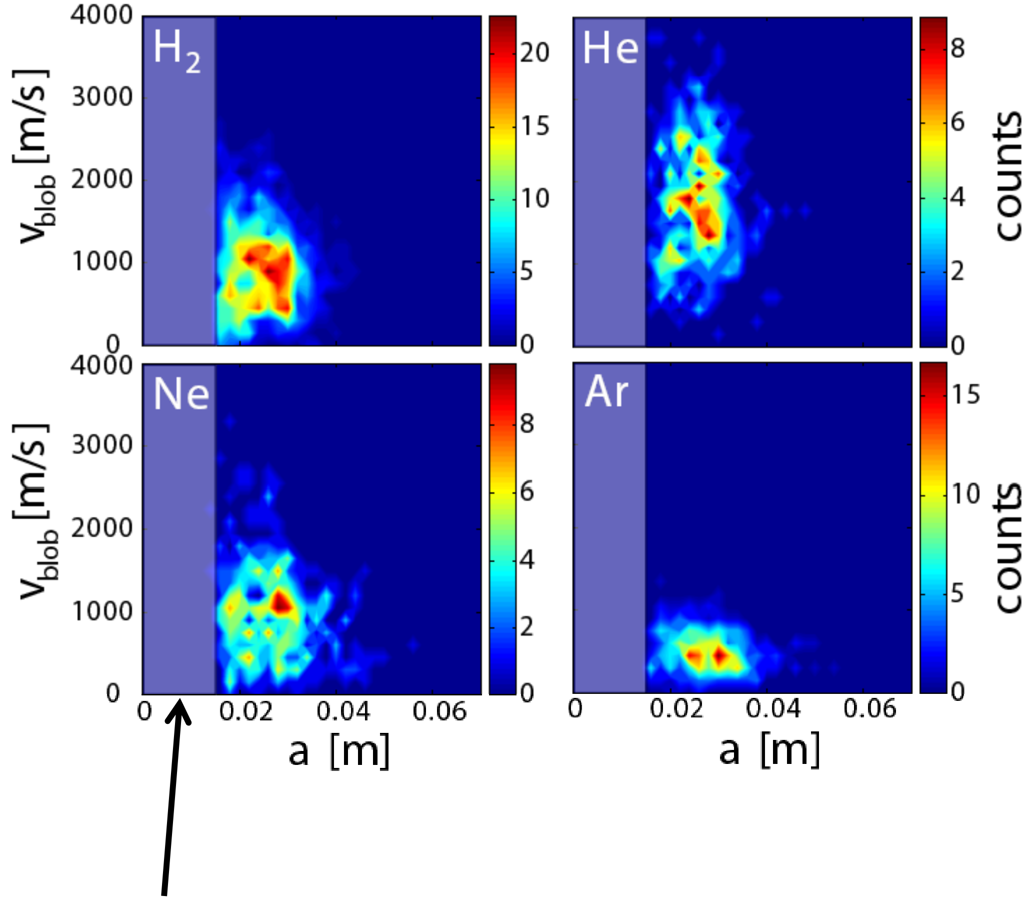




[1] S. H. Müller et al., POP 2006 [2] C. Theiler et al., submitted to PRL

Experimental results

- Joint probabilities of blob velocity versus vertical size shows a wide distribution with
  - Similar sizes in all gases
  - Similar values of $\delta n/n$
  - Significant differences in the typical velocity, ranging from 500 m/s (Ar) to 2000 m/s (He)

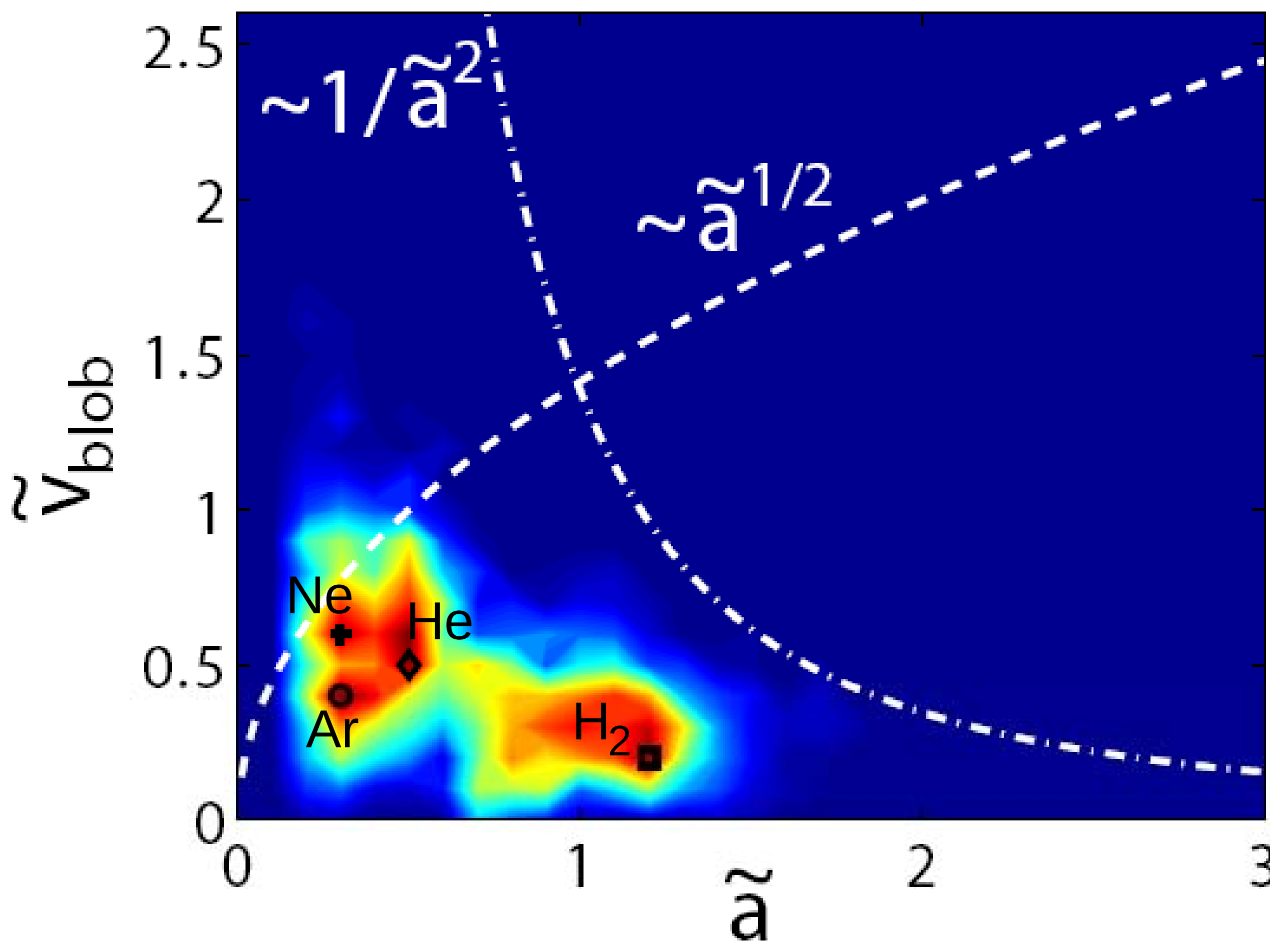


Range of blob sizes below diagnostic resolution

Comparison with 2D blob models

Experimental data in adimensional units

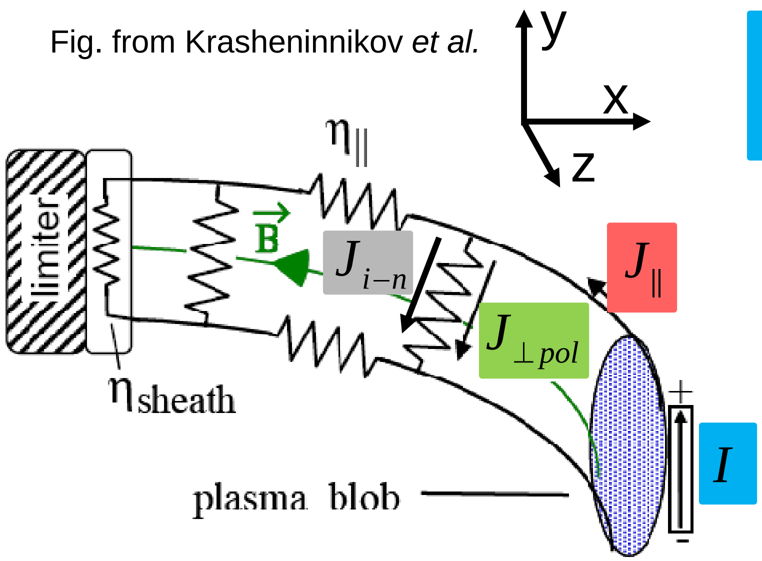
Damping due to
ion-polarization currents



Damping due to
parallel currents

Comparison with 2D blob models

Fig. from Krasheninnikov *et al.*



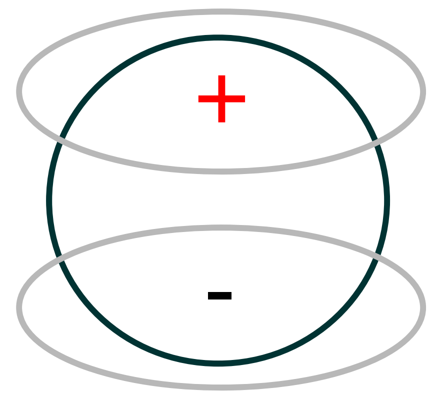
Vorticity equation

$$-sign(B_z)\frac{2c_s^2 m_i}{RB}\frac{\partial n}{\partial y} = \frac{nm_i}{B^2}\frac{D}{Dt}\nabla^2\phi - \frac{ne^2c_s}{T_eL}\tilde{\phi} + \frac{nm_i}{B^2}\nu_{in}\nabla^2\phi$$

Estimation of terms

$$\frac{\partial n}{\partial y} \sim \frac{-\delta n}{a} \qquad \frac{D}{Dt} \sim \frac{\sqrt{2c_s}}{\sqrt{Ra}} \text{ [2]}$$

$$\nabla^2\phi \sim \frac{-\tilde{\phi}}{a^2} \qquad \tilde{\phi} \sim Bv_{blob}a$$



$$\tilde{v}_{blob} = \frac{\sqrt{2\tilde{a}}}{1 + \sqrt{2}\tilde{a}^{5/2} + \tilde{\eta}\sqrt{\tilde{a}}}\frac{\delta n}{n}$$ [5]

Limits

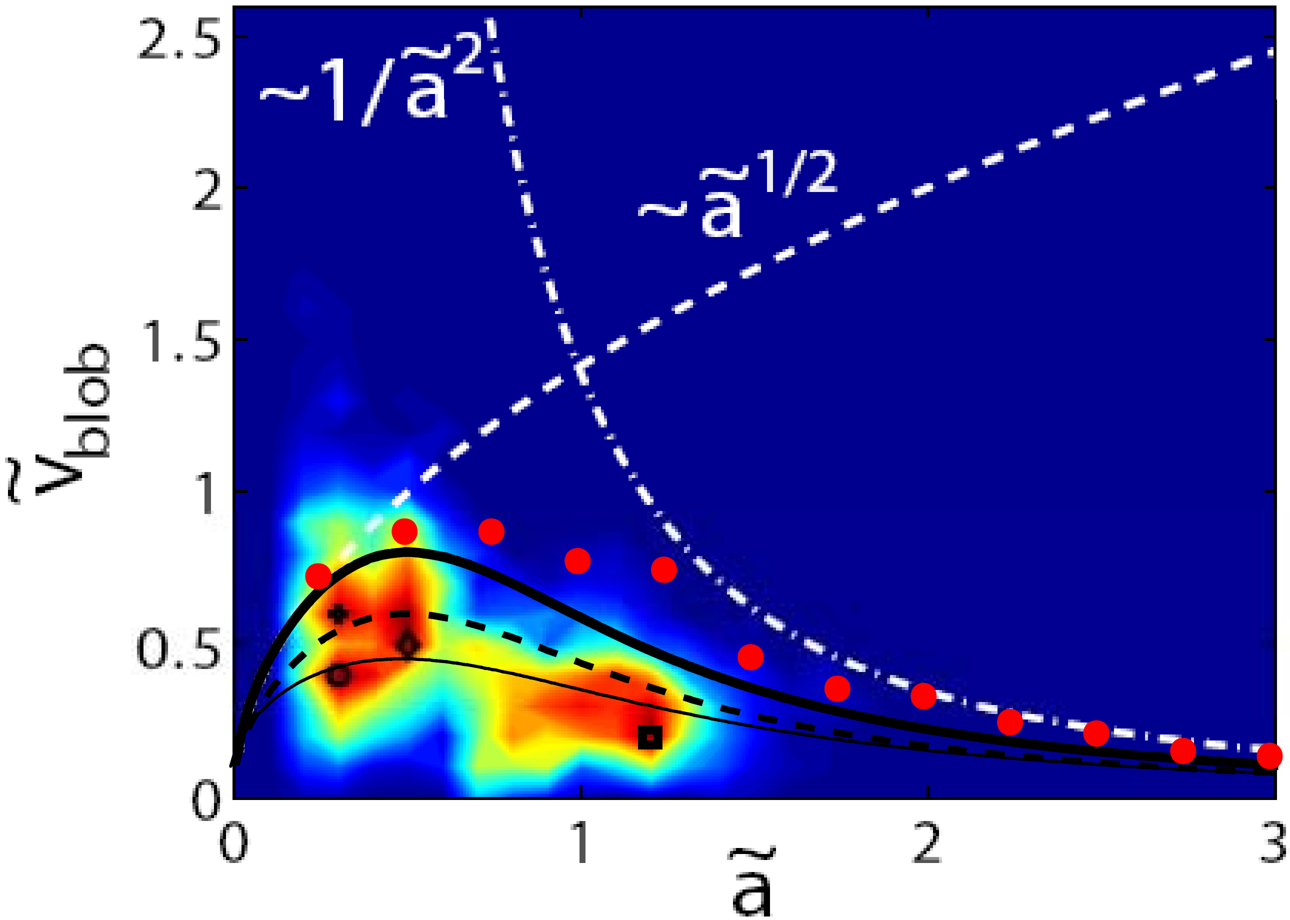
$$\tilde{v}_{blob} = \sqrt{2\tilde{a}}$$ [2,3]

$$\tilde{v}_{blob} = \frac{1}{\tilde{a}^2}$$ [1]

$$\tilde{v}_{blob} = \frac{\sqrt{2}}{\tilde{\eta}}$$ [4]

[1] S. I. Krasheninnikov, PLA 2001
[2] O. E. Garcia et al., POP 2005
[3] J. R. Myra and D. A. D'Ippolito, POP 2005
[4] N. Katz et al., PRL 2008
[5] C. Theiler et al., submitted to PRL

Agreement with 2D blob models



Parallel currents

+

Cross-field currents

+

Background plasma

+

Ion-neutral collisions

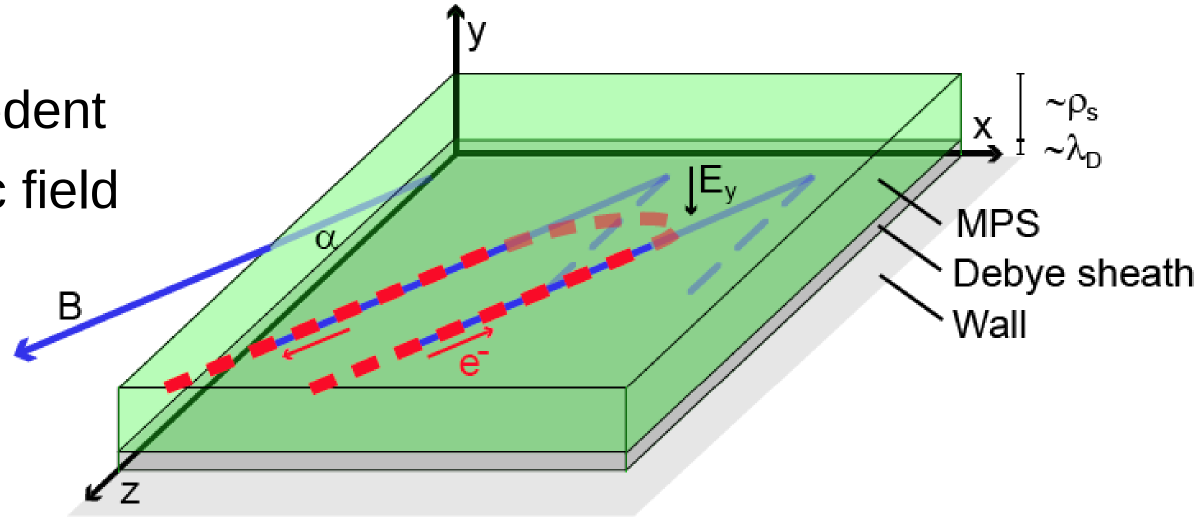
Numerical simulations from S. SUGITA et al.[1]

[1] S. Sugita et al., Plasma Fusion Res. **3**, 040 (2008)

Effect of wall tilt on blob velocity

Theoretical prediction[1,2]

Parallel electron current depedent on angle α between magnetic field lines and wall



~~α=π/2~~ α=<<1

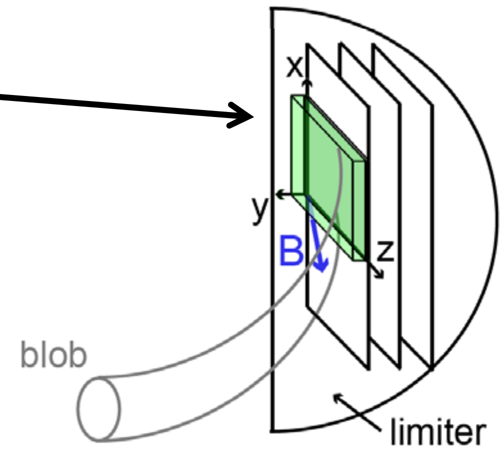
$$j_{||} = \frac{n_{se} e^2 c_s}{T_e} \tilde{\phi} + sign(B_z) \frac{1}{\alpha B} \frac{\partial p_e^{se}}{\partial x}$$

➡ α-dependence of parallel current boundary conditions

[1] R. H. Cohen and D. D. Ryutov, POP 1995
[2] R. H. Cohen and D. D. Ryutov, CPP 2006

Effect of wall tilt on blob velocity

Idea   Attaching plates **vertically** on the limiter



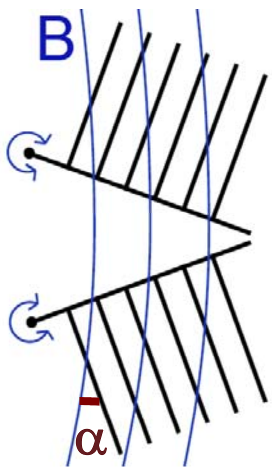
Limiter à configuration variable

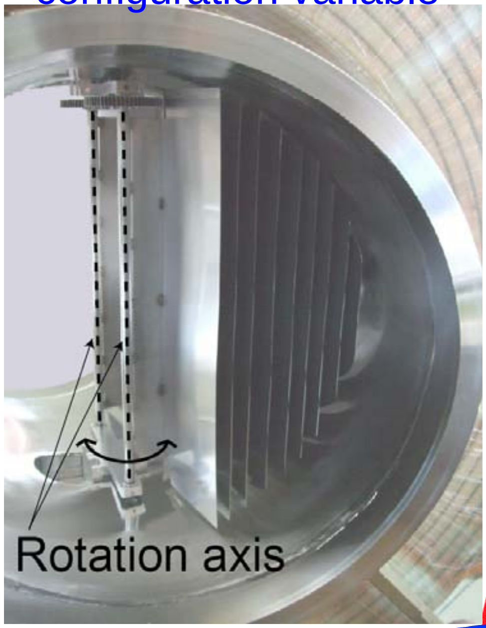
- ➡ In the magnetic pre-sheath, electrons are deviated in the **vertical** direction, in competition with ∇B and curvature drifts.
- ➡ Drive term in vorticity equation changed by a factor $1-R/(2L\alpha)$

Design

- Several plates are mounted perpendicularly on a limiter
- By pivoting the limiter around a vertical axis, we can achieve $|\alpha|\sim10^o$ and $|R/(2L\alpha)|\sim0.5$

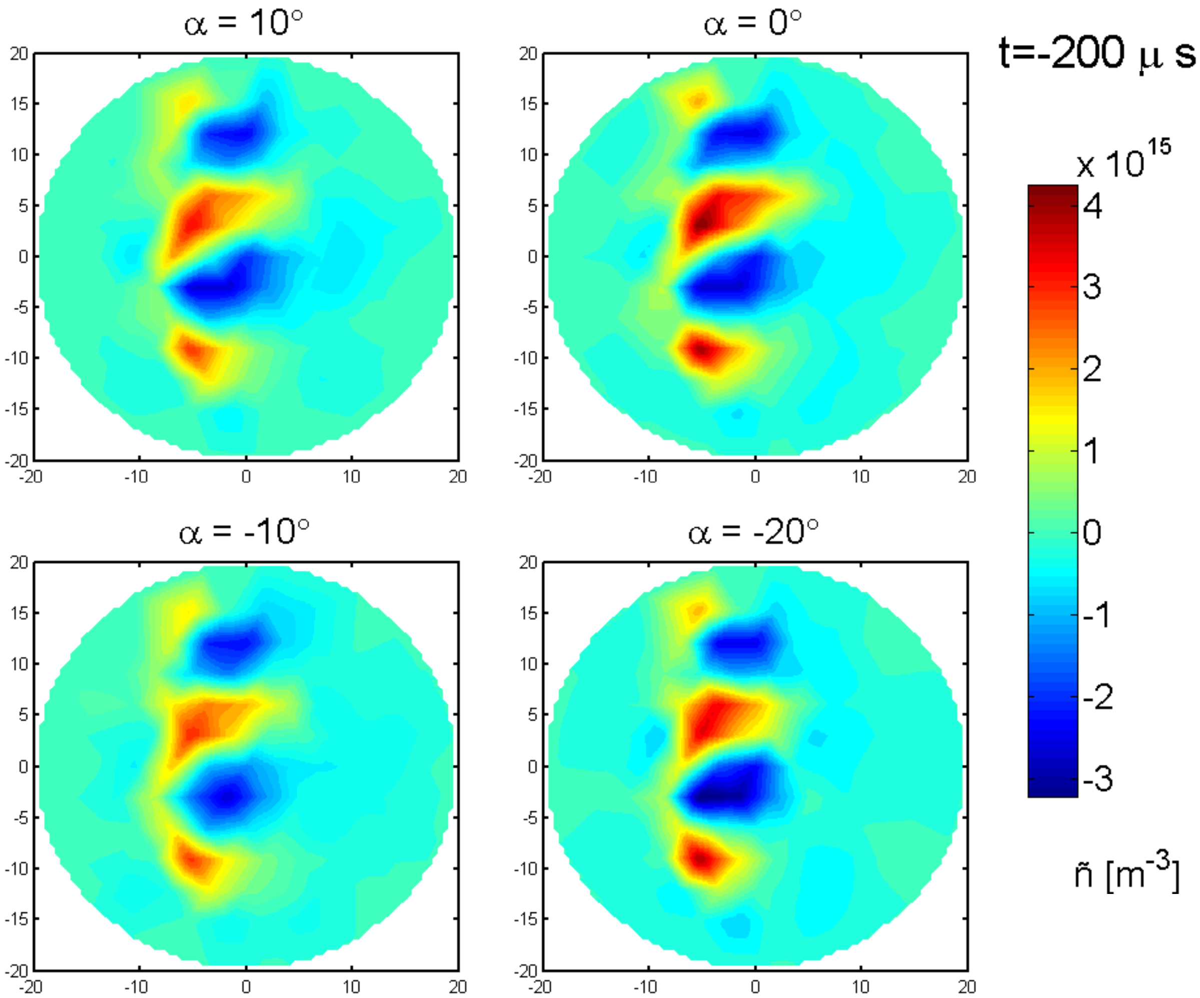
Schematic top view





First results show no dependence of blob velocity on angle α

Average blob dynamics in H_2 (conditional average over ~350 events) shows no significant difference for different values of α



Summary

- In situ measurements of blob motion in a simple geometry and a scan in the normalized blob size ã allowed for a quantitative comparison with 2D blob models

- A generalized expression for blob velocity was derived, which shows good agreement with experimental and simulation data. It includes
  - Parallel currents to the limiter
  - Cross-field ion polarization currents
  - Finite background plasma
  - Ion-neutral collisions

- Preliminary results with new tiltable-plate limiter suggest no effect of the angle between the magnetic field and the limiter on the blob velocity